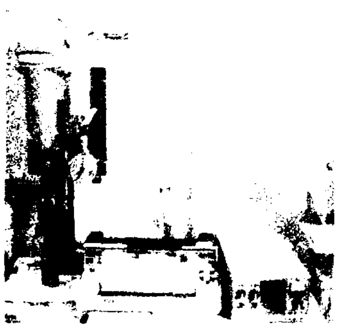
US Army Corps of Engineers



MISCELLANEOUS PAPER SL-90-1

EFFECTIVENESS OF MEMBRANE-FORMING CURING COMPOUNDS FOR CURING CONCRETE

by

C. L. White, T. B. Husbands

Structures Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

April 1990

Final Report

STRUCTURES LABORATORY

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

Under Civil Works Investigation Work Unit 32425

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188
Exp. Date Jun 30, 1986

1a. REPORT SECURITY CLASSIFICATION: Unclassified

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE:

3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S): Miscellaneous Paper SL-90-1

5. MONITORING ORGANIZATION REPORT NUMBER(S):

6a. NAME OF PERFORMING ORGANIZATION: USAEWES Structures Laboratory

6b. OFFICE SYMBOL (If applicable):

7a. NAME OF MONITORING ORGANIZATION:

6c. ADDRESS (City, State, and ZIP Code): 3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

7b. ADDRESS (City, State, and ZIP Code):

8a. NAME OF FUNDING/SPONSORING ORGANIZATION: US Army Corps of Engineers

8b. OFFICE SYMBOL (If applicable):

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c. ADDRESS (City, State, and ZIP Code): Washington, DC 20314-1000

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO	TASK NO.	WORK UNIT ACCESSION NO
			32425

11. TITLE (Include Security Classification): Effectiveness of Membrane-Forming Curing Compounds for Curing Concrete

12. PERSONAL AUTHOR(S): White, Charles L.; Husbands, Tony B.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final Report	FROM ______ TO ______	April 1990	41

16. SUPPLEMENTARY NOTATION: Available from National Techical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

Abrasion, (curing compounds) Absorptivity, Membrane-forming curing compounds, Moisture retention, Portland cement concrete, Portland cement mortar.

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A search was made for test methods to evaluate the effectiveness of curing concrete. Test methods that include water absorptivity (proposed ASTM test), capillary porosity, combined water, splitting tensile strength, and abrasion resistance were evaluated. Curing compounds having a wide range of water retention values and meeting the requirements of ASTM C 309-89 and CRD-C 300 were obtained for evaluation. A few curing compounds were prepared in the laboratory by diluting one of the CRD-C 300 curing compounds with the vehicle solvent furnished by the manufacturer to obtain curing compounds that would not meet the requirements of either specification.

The water-absorptivity test and an abrasion test developed in the laboratory were used to determine the effectiveness of the different curing compounds for curing concrete. Curing compounds meeting the requirements of ASTM C 309-89 were found to be as effective as curing compounds meeting the requirements of CRD-C 300 for curing concrete. Two of the

(Continued)

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION: Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL:

22b. TELEPHONE (Include Area Code):

22c. OFFICE SYMBOL:

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. ABSTRACT (Continued).

curing compounds that did not meet the specification requirements were also found to be effective based on the water-absorptivity test method. The abrasion test shows promise as a test method for evaluating the effectiveness of curing and is less time consuming than the water-absorptivity test method.

PREFACE

The study reported herein was conducted in the Structures Laboratory (SL), US Army Engineer Waterways Experiment Station (WES), under the sponsorship of Headquarters, US Army Corps of Engineers, as a part of Civil Works Investigation Work Unit 32425. Funds for the publication of this report were provided from those made available for operation of the Concrete Technology Information Analysis Center (CTIAC) at WES, SL. This is CTIAC Report No. 83.

The study was conducted under the general supervision of Messrs. Bryant Mather, Chief, SL; John Scanlon, former Chief, Concrete Technology Division (CTD), Kenneth Saucier, Chief, CTD, and Richard Stowe, Chief, Materials and Concrete Analysis Group. Mr. Charles White performed the testing. This report was prepared by Messrs. Charles White and Tony Husbands and was published at WES by the Visual Production Center, Information Technology Laboratory.

Commander and Director of WES is COL Larry B. Fulton, EN. Technical Director is Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
inches	25.4	millimetres
pounds (force) per square inch	0.006894757	megapascals
square feet	0.09290304	square metres
gallons	3.785412	litres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9)(F - 32). To obtain kelvin (K) readings, use: K = (5/9)(F - 32) + 273.15.

EFFECTIVENESS OF MEMBRANE-FORMING CURING COMPOUNDS FOR CURING CONCRETE

PART I: INTRODUCTION

1. The American Concrete Institute (ACI) Manual of Concrete Practice (ACI 1989) states that curing is the maintaining of a satisfactory moisture content and temperature in concrete during its early stages so that desired properties may develop. Curing is essential in the production of concrete that will have the desired properties. The strength and durability of concrete will be fully developed only if it is properly cured. There are many different materials and methods used for curing concrete which include: curing by continuous or frequent application of water, sheet materials, and membrane-forming curing compounds.*

2. Membrane-forming curing compounds are used extensively by the Corps of Engineers as a method for curing concrete. Membrane-forming compounds specified by the Corps include those compounds that comply with the requirements of the American Society of Testing Materials (ASTM) C 309-89 (ASTM 1989a) and CRD-C 300, Handbook for Concrete and Cement (US Army Engineer Waterways Experiment Station (USAEWES) 1949a). For most Civil Works projects curing compounds complying with CRD-C 300 are specified and for Military projects both ASTM C 309 and CRD-C 300 are specified. What concerns most Corps employees in choosing between ASTM C 309 and CRD-C 300 is the unit moisture loss requirement which is different for the two specifications. CRD-C 300 requires that the unit moisture loss be not greater than 0.031 g per sq cm after 7 days exposure to 10-mph air velocity at 100° F and 30 percent relative humidity for a coverage of 200 sq ft per gal. ASTM C 309 requires that the unit moisture loss be not greater than 0.055 g per sq cm after 72 hours at 100° F and 30 percent relative humidity. Curing compounds complying with the requirements of ASTM C 309 are less expensive and more available than curing compounds complying with the requirements of CRD-C 300.

3. No data were found to confirm that curing compounds meeting ASTM C 309 are as effective as curing compounds meeting CRD-C 300 for curing comply

---

* If the ambient conditions are favorable, no action of any sort will be needed to achieve proper curing (ACI 1989).

concrete. There was, therefore, a need to evaluate curing compounds which with the requirements of the two specifications to determine their effectiveness in curing concrete and establish a satisfactory value for water retention requirements of curing compounds. Based on this evaluation a cost-effective decision can be made to determine the specification to be used by the Corps.

4. Curing compounds having different water retention values (covering a wide range) and which met the requirements for both specifications and a few that failed ASTM C 309 requirement were obtained for evaluation. Test procedures for evaluating the effectiveness of curing concrete were investigated, they include: water absorptivity, capillary porosity, splitting tensile strength, abrasion resistance, and combined water. Based on this investigation the water absorptivity test was used to evaluate the effectiveness of curing, and an abrasion test was developed to confirm the effectiveness of curing.

PART II: MATERIALS

Cement and Fine Aggregate

5. A Type I portland cement designated WES-48, C-1 and a graded silica sand from Ottawa, IL, C-109, was used in preparing the mortar for testing. The test report for the portland cement is shown in Table 1.

Membrane-Forming Curing Compounds

6. Nine curing compounds obtained from four manufacturers were used for this study. One manufacturer submitted a sample of the volatile thinner (mineral spirits) as requested by WES. The volatile thinner was used to dilute the curing compound to lower the solids content to obtain various water retentions. The description of each curing compound used for this study is shown in Table 2. The curing compound, WES-CC-2R, was diluted with the thinner to obtain lower vehicle solids contents and three curing compounds, WES-CC-2R6, WES-CC-2R4 and WES-CC-2R3, were prepared by WES by making the dilutions. The designation and dilution factor are shown.

	Percent by Weight	
Designation	Curing Compound	Thinner
WES-CC-2R6	60	40
WES-CC-2R4	40	60
WES-CC-2R3	30	70

7. The curing compound were tested for water retention and non-volatile content in accordance with one or both test methods ASTM C 156-89 (ASTM 1989e) and CRD-C 302 (USAEWES 1949b). The test results are shown in Table 3.

PART III: TEST METHODS

Search for Appropriate Tests

8. A search was made to find tests that would be appropriate in determining the effectiveness of curing of concrete. Senbetta (1981) investigated a number of test methods which were: the absorptivity test, nonevaporable water determination, and the abrasion test (ASTM C 418-89) (ASTM 1989b). The absorptivity and the abrasion tests were found to be sensitive and reproducible indicators of the quality of mortar samples tested. The non-evaporable water test did not produce the expected results. These tests are described in Senbetta's report. Other test methods considered or tried included: capillary porosity, combined water, splitting tensile strength of mortar cores, and abrasion resistance using rotating cutting wheels and a core barrel.

Descriptions of Tests

Absorptivity test

9. The test used for this investigation was a proposed ASTM test (ASTM 1988)* except for a few modifications. A small table saw was used rather than the low-speed precision saw specified in the proposed test method. A jig was built for the saw to hold the mortar core for cutting. The saw and jig is shown in Figure 1. The mortar test slab was smaller in size measuring 7 by 7 by 2-5/8 in. The test specimens (layers of mortar 1 cm thick) were sliced off the core within 1 hr after coring, and placed immediately in methanol. Water was used as the coolant for the saw rather than ethanol as specified. The authors were concerned about the flammability of the ethanol and the ethanol was removing the protective paint coating on the saw. The diameter of the cores taken from the mortar test slabs were 1 and 2 in. as specified. The test mortar slabs were allowed to cure 7 days before coring.

Capillary porosity

10. Test specimens were prepared as described for the absorptivity

* This proposal was withdrawn and does not appear in the 1989 ASTM Book of Standards.

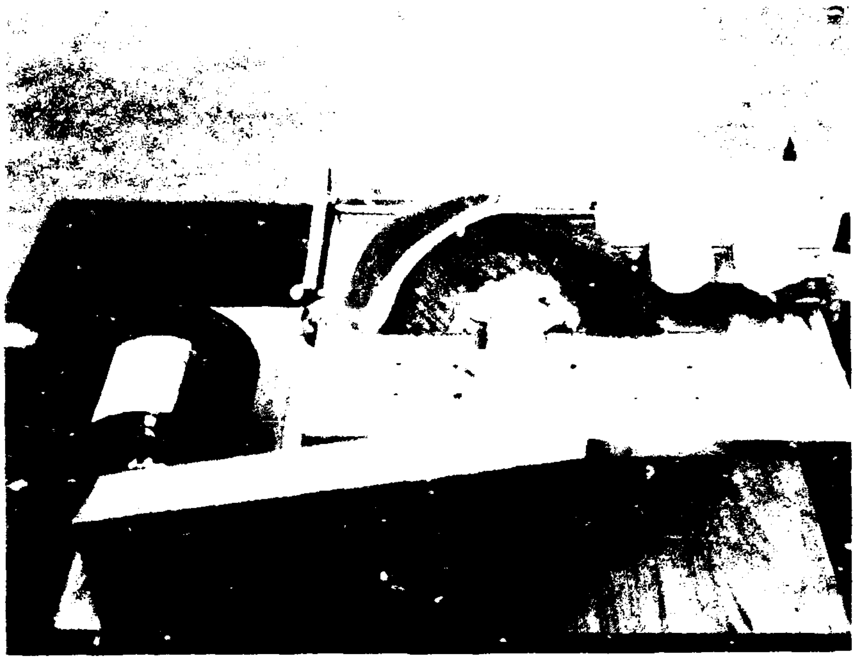


Figure 1. Table saw and jig used for preparing water absorptivity test specimens

test. Discs 1 cm thick sliced from the cores were tested for capillary porosity using Figg's method (Figg and Bowden 1971). Two disks 1 cm thick were sliced from the core. One disk was sliced off the top of the core 0.5 cm below the surface. The other disk was sliced off the bottom the core 4.8 cm below the surface. The test specimens were immersed in a vacuum desiccator and the pressure reduced to 13.29 KPa by means of a vacuum pump. The test specimen was left immersed in the trichlorethane for 4 hr. The test specimen was removed and the excess solvent wiped from the surface. The test specimen was immediately placed into a tared polyethylene bag and weighed. The mass (g) of the 1,1,1-trichlorethane absorbed by the specimen was divided by the density of 1,1,1-trichlorethane and the porosity reported as $cm^3/100$ g.

Combined water

11. The combined water of the mortar was determined using Figg's method (Figg and Bowden 1971). The layers of mortar prepared from the absorptivity test and small cylinders cast from the mortar were tested for combined water. The test method consists in igniting a dried powdered sample of the mortar at 1,830° F in a stream of nitrogen gas and weighing the evolved water after absorption on dried magnesium perchlorate.

Splitting tensile strength

12. Test mortar slabs were cast and subjected to different curing environments for 7 days. After this curing period four cores 2 in. in diameter were taken from the slabs. The cores were immersed in lime water 4 hr before testing. The cores were tested in accordance with ASTM C 496-86 (ASTM 1989c) except that the bearing strips were strips of aluminum 1/8 in. thick and 1/4 in. wide. The plywood strips specified were found to be unsatisfactory for small cores such as the ones tested.

Abrasion tests

13. Two abrasion tests were used to determine the abrasion resistance of mortar test specimens which were subjected to different curing environments. The rotating-cutter method, ASTM C 944-80 (ASTM 1989d), was used to measure the abrasion resistance of the surface of mortar test specimens. Another method was developed which could measure abrasion rates at greater depths into the mortar test specimen. This test was developed based on early experience when taking cores from the mortar test specimen. It was observed that coring was faster with less force necessary when coring mortar test specimens that were not cured. This test consisted of attaching a 2-in. diamond-core barrel to a drill press and placing a 4-lb mass ("weight") to the arm of the drill press. A linear variable differential transformer (LVDT) was attached to the drill press to measure the distance the core barrel traveled. The LVDT was connected to a recorder so that depth with time could be recorded. The test apparatus is shown in Figure 2. Mortar slabs were tested that had been moist cured for 7 days and slabs that were placed in a controlled environment at 100° F and 30 percent R.H. A significant difference in depth of abrasion with time was observed for the moist cured and uncured mortar slabs.

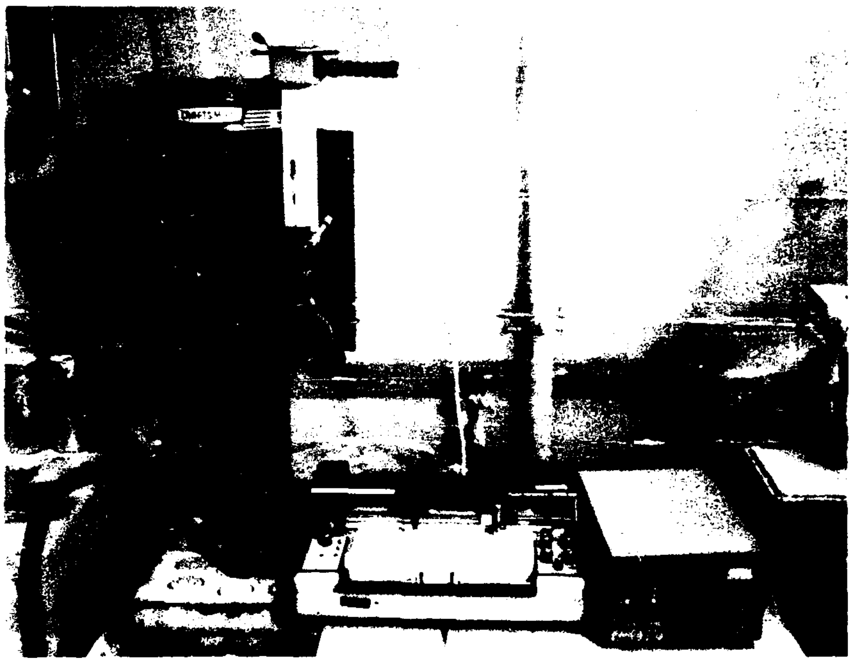


Figure 2. Core barrel abrasion tester

PART IV: EVALUATION OF TEST METHODS

14. All test methods were evaluated by testing mortar slabs which had been cured in different environments for 7 days. The test mortar slabs were prepared as specified in the proposed ASTM procedure except that the water to cement ratio and flow were changed slightly for some of the tests. For most evaluations of the test methods two test mortar slabs were cast from the same batch of mortar. For some of the earlier test, three test mortar slabs were cast from the same batch of mortar. One of the slabs was placed into the curing compound testing cabinet at a temperature of 100 ± 2° F, relative humidity of 30 ± 3 percent, and an air velocity of 10 ± 3 mph. The other slab was moist cured in a room maintained at 73 ± 3° F with a relative humidity of not less than 95 percent. A few of the slabs were cured in laboratory air 73° F ± 3 and 50 percent relative humidity, and in an environmental chamber conditioned at 100° F and 30 percent relative humidity. The tests were then evaluated by comparing differences in the moist cured mortar test specimen, and the mortar specimens cured in other environments.

Absorptivity Test

15. The first evaluation of this test procedure was performed by taking two 1-in. cores from the test mortar slabs and measuring absorptivity at five depths from the surface. Three mortar slabs were prepared from each batch of mortar which was mixed in a pail mixer. Each of the three mortar slabs were cured in different environments; moist cured, curing compound testing cabinet, and in laboratory air. The mortar slabs were allowed to cure for 7 days at these conditions, then cored. The test specimens were sliced off the cores and placed in methanol for at least 24 hr or longer before testing. Three mortar slabs were cast and approximately one week later three more slabs were cast and designated as test slabs 1 through 6. These mortar slabs were tested and the results are shown in Table 4.

16. These first test results indicated that there was a significant difference in the absorptivity values between cores taken from the same mortar specimen. There was also a greater difference in the absorptivity values at different depths for cores taken from specimens cured under the same

conditions. The greatest differences were found in the mortar specimens cured in the curing compound test cabinet which would be expected because of higher absorptivity values. The greatest difference in two cores were found in specimen No. 3. The difference in absorptivity (Ka) for the top slice (0.5 cm in depth) and bottom slice (4.8 cm in depth) for the two cores was 15 and 2 x 10^{-6} cm^2/sec. A large difference in absorptivity was noted in the two cores taken from specimen No. 4 which was moist cured.

17. The variation of absorptivity values between cores and between depths could have attributed to the following:

- a. Mortar improperly mixed due to pail mixer.
- b. Saw used was not as precise as the one specified.
- c. Mortar not consolidated well leaving some voids on test surface of sliced mortar layers.

When observing the sliced layers of mortar from the cores, there appeared to be some surface areas that contained some small areas of paste without fine aggregate indicating improper mixing. Some of the slices of mortar contained more voids on the surface (entrapped air).

18. Four mortar slabs were cast later and designated test slabs 7 thru 10) and the only difference in preparation or testing was that a Hobart mixer was used to mix the mortar. Two mortar slabs were cast from each batch of mortar. Two of the mortar slabs were placed in the curing compound test cabinet, one mortar slab left in laboratory air, and one mortar slab moist cured. After 7 days the mortar slabs were cored and the cores sliced at different depths before testing. The test results are shown in Table 5.

19. There appeared to be less variation between absorptivity values for different cores and at different depths for the second run using the Hobart mixer. The following tabulation is a comparison of the two different runs for the specimens cured in the curing compound testing cabinet:

			Absorptivity (x 10^{-6} cm^2/sec) Depth from surface, cm				
Run			1	2	3	4	5
1	Mean	X	18.0	14.3	9.6	7.7	5.1
	Standard deviation	σ	6.3	8.4	2.7	3.8	3.3
	Coefficient of variation	CV	35.0	59.0	28.0	49.0	65.0
2	Mean	X	20.4	8.3	6.7	4.7	3.7
	Standard deviation	σ	5.5	2.6	1.5	1.4	1.1
	Coefficient of variation	CV	27.0	31.0	22.0	30.0	30.0

The effect of different curing conditions on change in absorptivity at different depths for the sample specimens in Run No. 2 is shown in Figure 3.

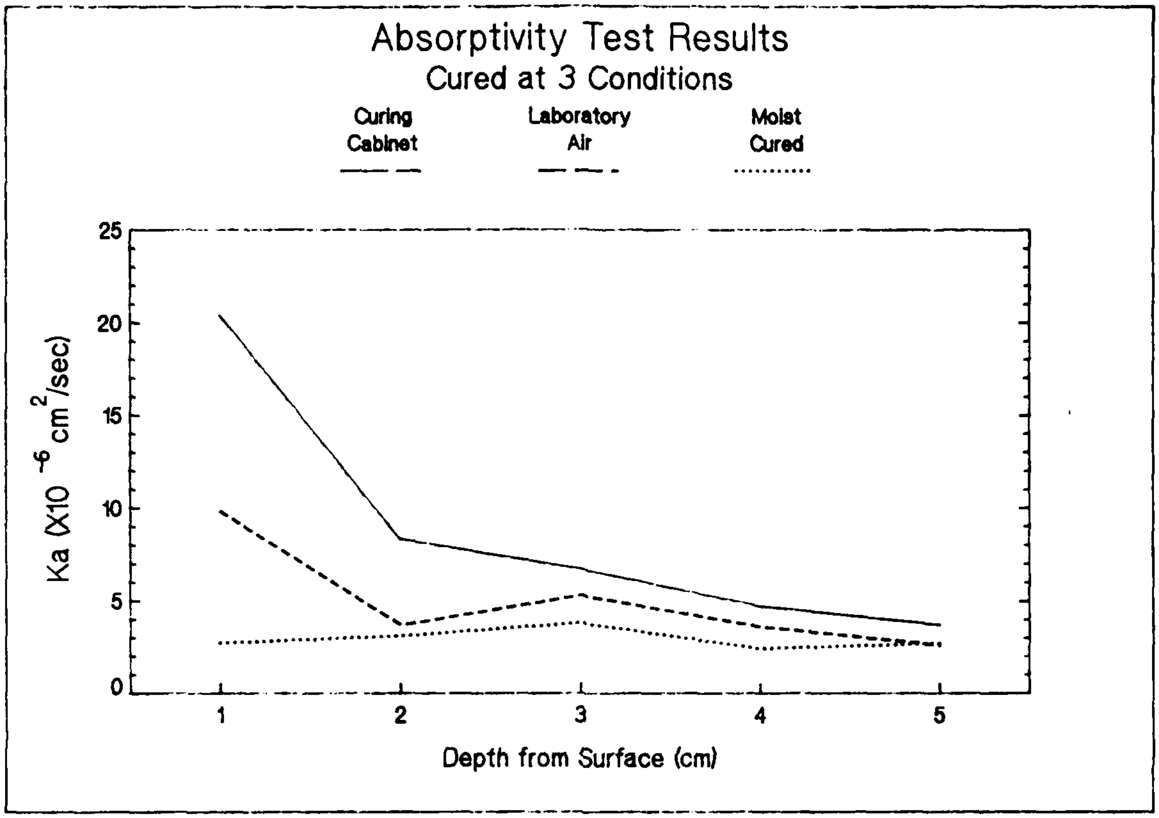


Figure 3. Absorptivity at different depths for different curing conditions

20. When evaluating the capillary porosity test method, the test results indicated that less variation was found between the capillary porosity results within a mortar slab when larger test specimens were prepared. The core size was increased from 1 to 2 in. which increased the surface area of the absorptivity test specimen to 3.14 sq in. or 4 times larger than the test specimens prepared from the 1 in. cores. The water-cement ratio (W/C) was increased from 0.44 to 0.45 and the sand-cement ratio (S/C) was decreased from 2.90 to 2.70 for preparing most of the mortar slabs. For the test absorptivity readings were obtained near the top of the mortar slabs (0.5 cm from top surface) and near the bottom of the mortar slabs (4.5 cm from top surface) and will be referred to as top and bottom for comparisons.

21. Four mortar slabs were cast and two were moist cured and the other two were placed in the curing compound cabinet for 7 days. Cores were then taken from the mortar slabs, sliced to obtain test specimens near the top and

bottom and tested for absorptivity. The results are shown in Table 6. A large difference in the absorptivity values (24.8 and 16.2 x 10^{-6} cm^2/sec between the top and bottom were obtained for the mortar slabs aired in the curing compound test cabinet. A small difference in the absorptivity values (0.5 and 0.2 x 10^{-6} cm^2/sec were obtained for the moist cured mortar slabs.

22. Eight mortar slabs were cast and four were moist cured and the other four were placed in the curing compound test cabinet for 7 days. Four cores were taken from each mortar slab for testing to determine difference in absorptivity from top to bottom of the mortar slabs. The test results are shown in Table 7. A large difference in the absorptivity values *8.5 to 11.7 x 10^{-6} cm^2/sec) was obtained from top to bottom for the mortar slabs cured in the curing compound test cabinet. Only slight differences in the absorptivity values (0.1 to 0.3 x 10^{-6} cm^2/sec) were obtained for the moist cured mortar slabs. The difference found for test slab No. 21 may be attributed to the location it was placed in the test cabinet. Some difference in the rate of evaporation does exist for different locations in the test cabinet.

23. Four mortar slabs were cast, two each cast 2 weeks apart, and placed in a controlled cabinet at 100° F and 30 percent R.H. After 7 days at these conditions the mortar slabs were tested for absorptivity and the results are shown in Table 8. Very little differences in absorptivity from top to bottom were observed for the four slabs tested.

Capillary Porosity

24. Mortar slabs were cast using the mortar mixture given in the proposed ASTM test method for absorptivity. The mortar slabs were placed in the curing compound test cabinet and moist curing room for 7 days, then cored and the cores cut into disk for testing. The top and bottom disk were tested for capillary porosity. The first tests were performed by using different reduced pressures for the desiccator containing the 1,1,1-trichloroethane. The reduced pressures used in the evaluation of the test were 2 in., 20 in., and 28 in. of mercury. The test results are shown in Table 9.

25. These test indicate that the lower pressures 20 and 28 in. Hg would not be satisfactory because of the higher capillary porosity values obtained. These higher values were attributed to microcracks being formed in the paste

because of the lower pressures. When comparing the test results for the discs soaked under pressures measuring 2 in. Hg, the difference in the top and bottom disks were much greater for the slabs cured in the curing compound cabinet.

26. Later additional capillary porosity tests were performed on mortar slabs cast from a mortar mixture with a W/C of 0.45 and a S/C of 2.70. The reduced pressure measuring 2 in. Hg was used when soaking the disks. A total of 10 mortar slabs were cast over a 2-month period and 5 of the slabs were moist cured and 5 were cured in the curing compound test cabinet for 7 days. The test results are shown in Table 10.

27. The test results indicated that the capillary porosity test can be used as a measure for determining if mortar was effectively cured. The difference in the capillary porosity from top to bottom for the mortar slabs cured in the curing compound cabinet ranged from 1.75 to 2.40 cm^3/100 g compared to a range of 0.04 to 0.49 cm^3/100 g for the moist cured slabs. The test method takes longer to complete than the absorptivity test method because of the time of soaking in the 1,1,1-trichlorethane.

Combined Water

28. Two 2-in. cubes of mortar were cast and one cube was moist cured and the other cube placed in a controlled cabinet at 100° F and 30 percent relative humidity. The mortar that was moist cured was found to contain 4.94 percent combined water and the mortar that was placed in the cabinet was found to contain 3.91 percent combined water. Slices of the mortar cut from the cores of the test specimens prepared for capillary porosity test were analyzed for combined water. The top slices from specimens moist cured and from specimens placed in the curing compound cabinet were analyzed. Two slices of the mortar from the moist cured specimen were found to contain 3.72 percent combined water, and the two slices from the uncured specimen were found to contain 3.32 percent. A difference in combined water for cured and uncured mortar was evident but because of the small difference it would be difficult to use as a parameter in determining the effectiveness of cure.

Splitting Tensile Strength

29. Four of the mortar slabs were cast and two were moist cured and the other two placed in the curing compound cabinet. After 7 days conditioning in the two environments, three 2-in.-diameter cores were taken from each of the slabs. The cores were placed under water for 4 hr before being tested for splitting tensile strengths. The individual splitting tensile strengths of the 12 cores is shown in Table 11. A difference in splitting tensile strengths of the mortar conditioned by moist curing and in the curing compound was noted. The moist cured specimens had a splitting tensile strength of 310 psi compared to 250 psi for the specimens placed in the curing compound cabinet (average of 6 cores each). There was only a small difference in splitting tensile strength of two mortar slabs conditioned differently (300 psi moist cured and 270 psi curing compound cabinet). Due to this small difference it would be necessary to test more than one mortar slab at a particular condition for comparing differences in splitting tensile strength.

PART V: TEST RESULTS FOR MEMBRANE-FORMING CURING COMPOUNDS

Absorptivity Test Method

30. The absorptivity test method was selected to evaluate the effectiveness of the various curing compounds to cure mortar test specimens. The mortar test slabs used for the evaluation of the absorptivity test methods and the mortar mixture containing the W/C of 0.45 and S/C of 2.70 were used for this evaluation. The mortar test slabs were coated with the curing compounds using an application rate of 200 sq ft/gal, the same application rate used when measuring the water retention. Four mortar slabs were cast when testing the individual curing compounds. Two of the slabs were coated with the curing compound. After coating three of the slabs were placed in the curing compound cabinet specified in CRD-C 302 (USAEWES 1949b). The other slab was stored in a moist curing cabinet. The test slabs were conditioned in the two different environments for 7 days before testing. Four 2-in. cores were taken from each slab and a 1-cm-thick disc sliced from the top and bottom measured for absorptivity. The average of the absorptivity for the four disc was reported.

31. The test results are shown in Figures 4 through 12. The test results for the two curing compounds, WES-CC-1R and WES-CC-2R, formulated to comply with the requirements CRD-C 300 (USAEWES 1949a), are shown in Figures 4 and 5. The Ka values of the top and bottom of the mortar test specimens coated with the two curing compounds was found to be equal to or less than the moist cured test specimen. The test results for three curing compounds, WES-CC-3R, WES-CC-8R, and WES-CC-9R, formulated to comply with the requirements of ASTM C 309 (ASTM 1989a), are shown in Figures 6, 8, and 9. The Ka values obtained for the top and bottom of the test specimens coated with these curing compounds were very similar to the absorptivity values obtained for the moist cured test specimens. The Ka values for the bottom of the test specimens coated with curing compounds was in every case lower than the moist cured test specimen. The absorptivity of the bottom was higher than the top for all moist cured specimens. There is no explanation for this phenomenon, except that vapor pressure might contribute to the difference. The top side of the coated test specimens were slightly higher than the moist cured, but no significant difference from top to bottom was observed.

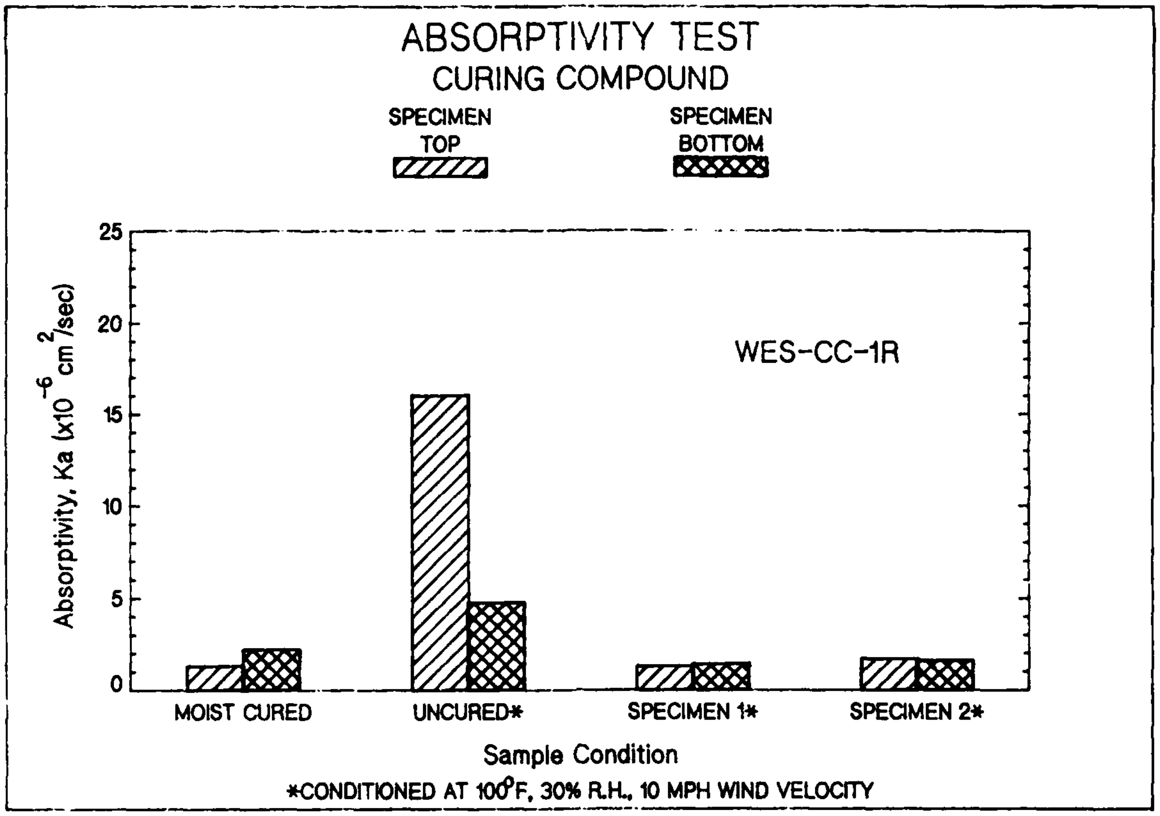


Figure 4. Absorptivity test results for curing compound WES-CC-1R

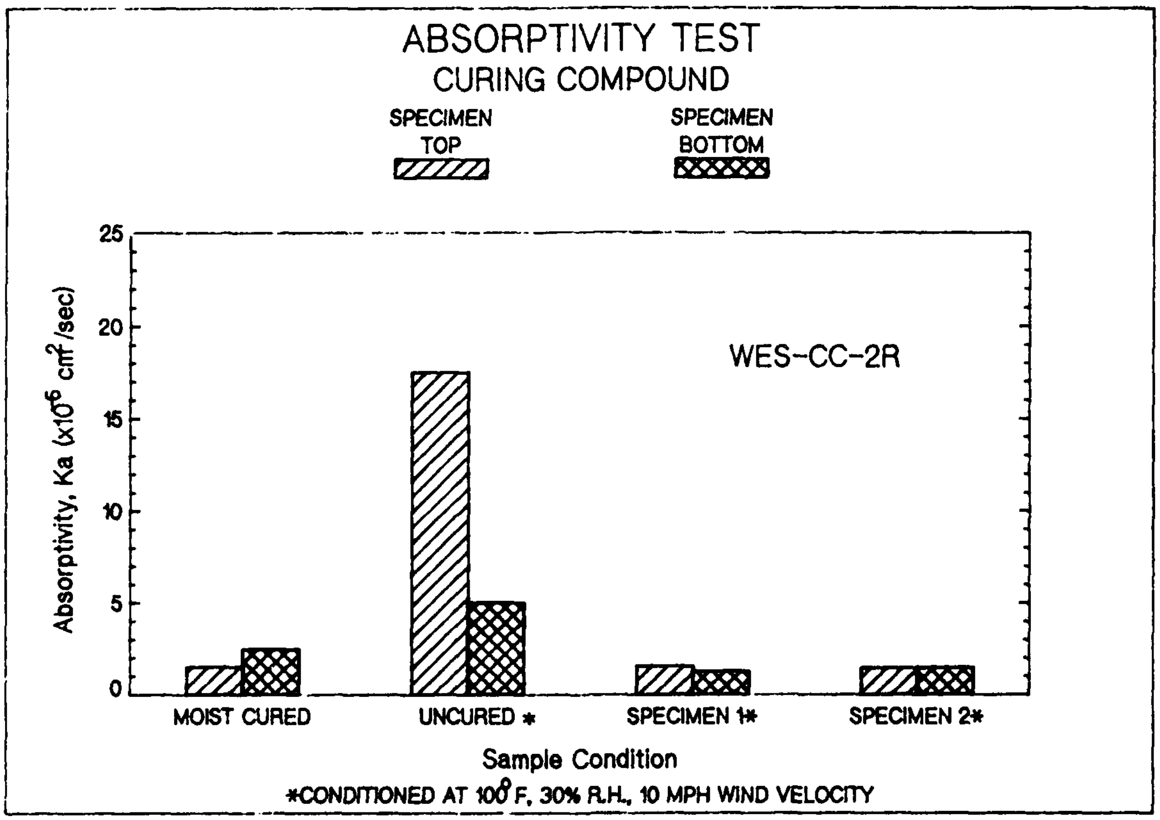


Figure 5. Absorptivity test results for curing compound WES-CC-2R

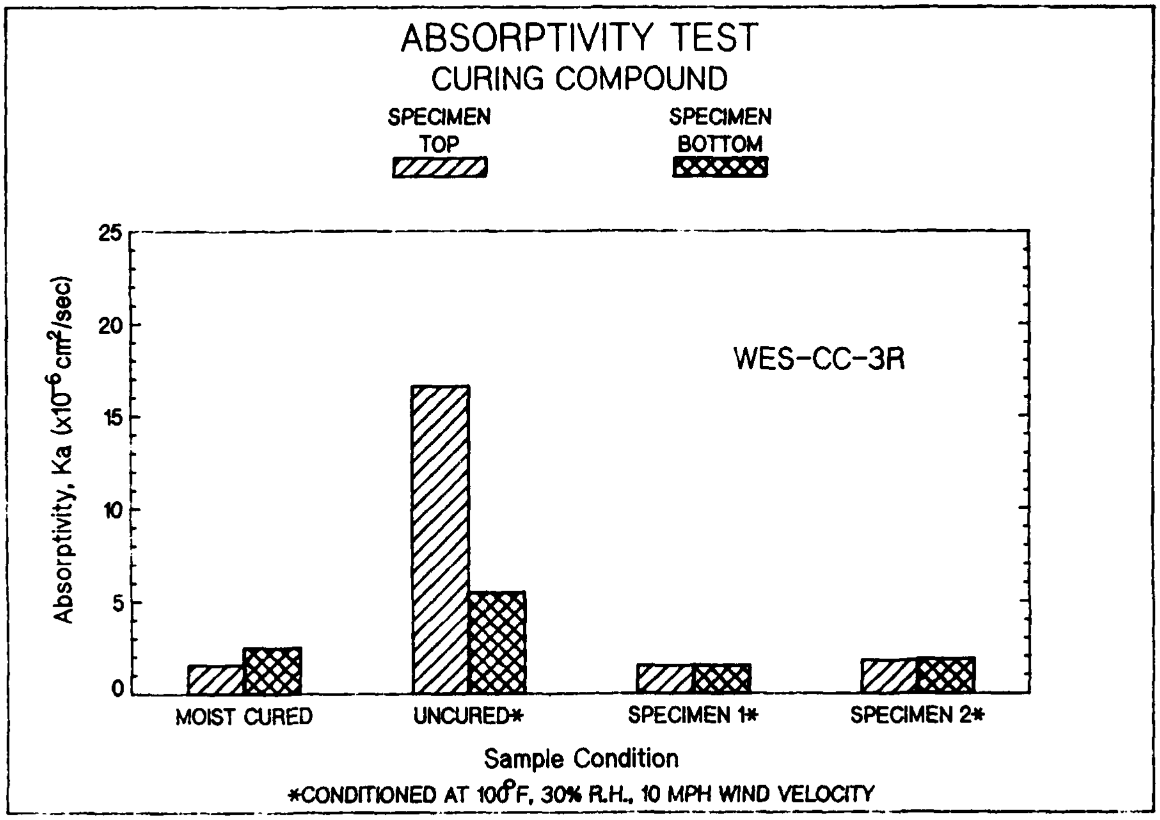


Figure 6. Absorptivity test results for curing compound WES-CC-3R

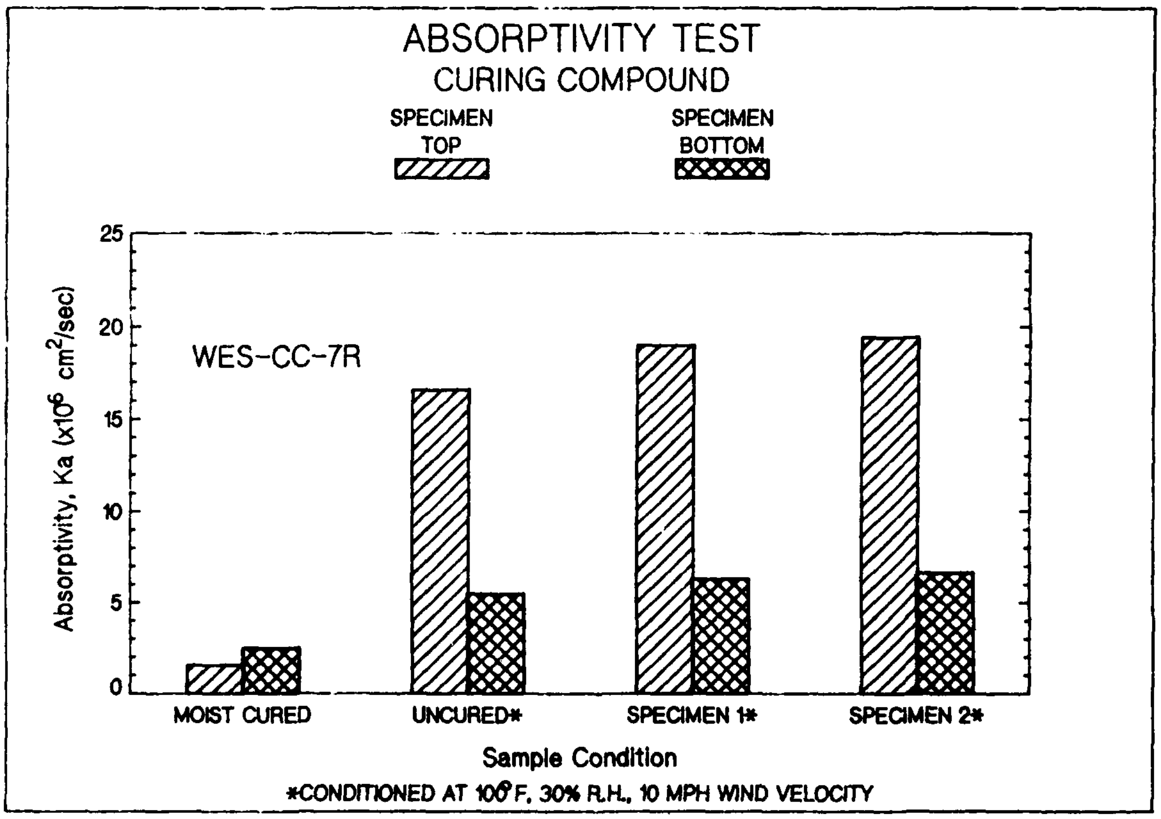


Figure 7. Absorptivity test results for curing compound WES-CC-7R

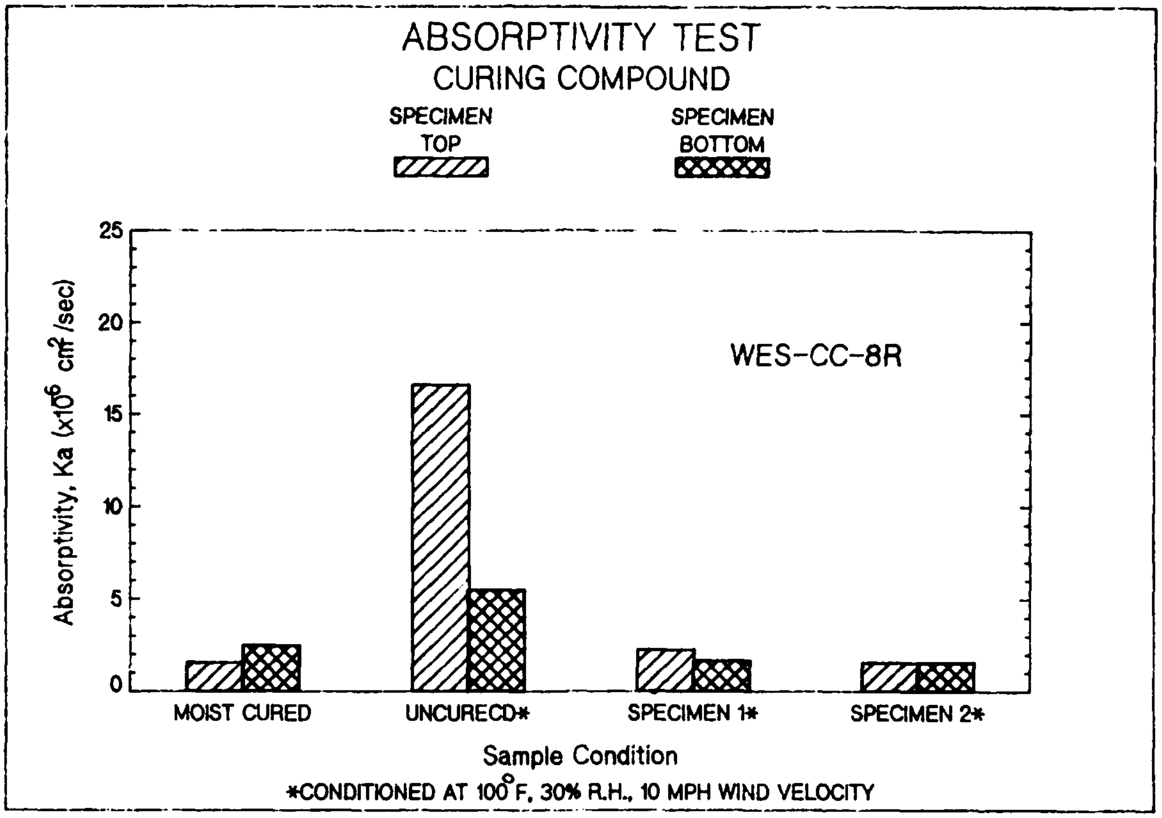


Figure 8. Absorptivity test results for curing compound WES-CC-8R

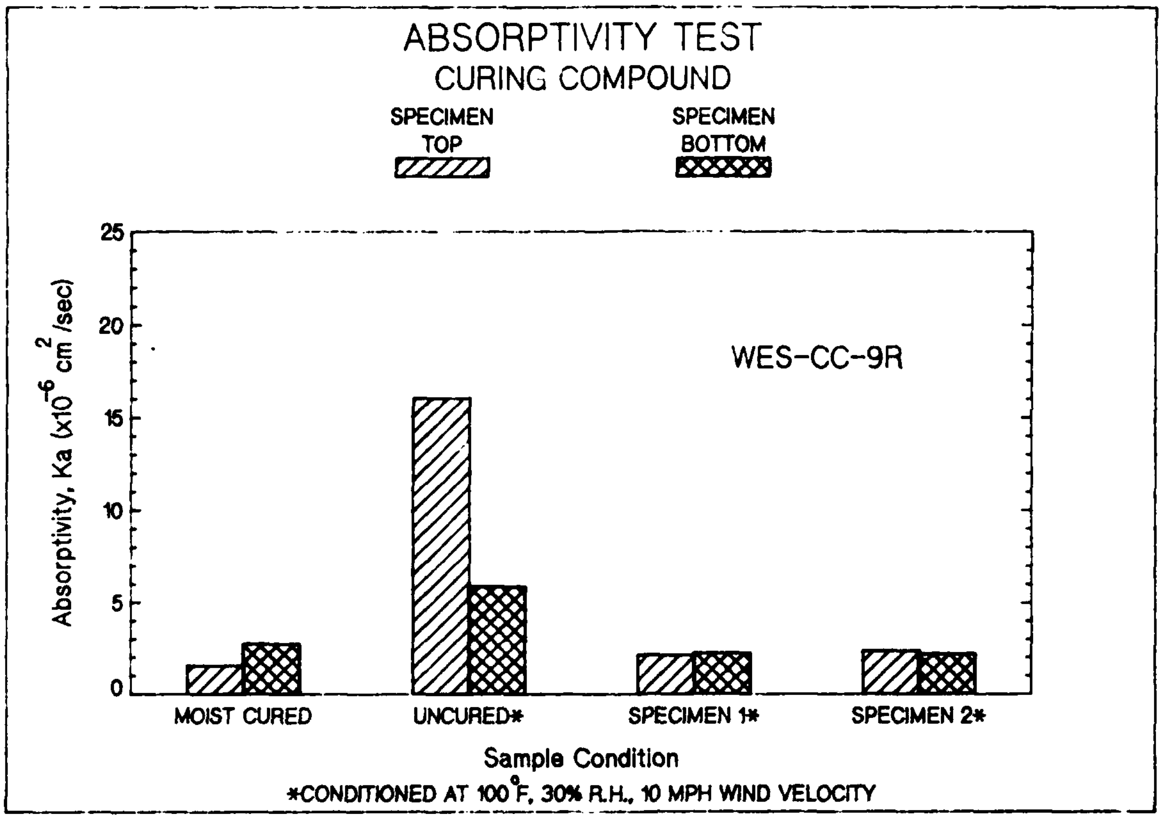


Figure 9. Absorptivity test results for curing compound WES-CC-9R

32. Test results for WES-CC-7R are shown in Figure 7. This material was not promoted by the manufacturer as a curing compound. The recommended usage is as a hardener and sealer. Some manufacturers of similar materials (silicates dissolved in water) have promoted these materials for curing concrete. The material was tested in accordance with ASTM C 156 (ASTM 1989e) and the unit moisture loss was 0.17 g/cm^2 which would fail the requirement of ASTM C 309 (ASTM 1989a) which is 0.055 g/cm^2. A large difference of approximately 12 x 10^{-6} cm^2/sec Ka was observed between the top side and bottom indicating that this material is unacceptable. The ASTM proposed test method suggests that a difference between the top and bottom Ka > 3.7 x 10^{-6} indicates marginal or unacceptable performance. Since the molds used for these test were approximately 1 in. less in depth than the one specified by the ASTM proposed test method, a Ka range from top to bottom less than the one specified could be expected.

33. The test results for the three curing compounds made at WES by diluting WES-CC-2R with mineral spirits are shown in Figures 10, 11, and 12. Test results for WES-CC-2R6 is shown in Figure 10. This curing compound failed to meet the unit moisture loss requirement of ASTM C 309. The Ka values for the top and bottom was nearly identical to the moist cured test specimen indicating acceptable performance. Since this curing compound was found to have unit moisture loss of 0.068 g/cm^2 and the unit moisture loss was only slightly higher than ASTM C 309 requirement of 0.005 g/cm^2 the difference in Ka value from top to bottom was not unexpected.

34. The test results for WES-CC-2R4 is shown in Figure 11. This curing compound had a unit moisture loss of 0.098 g/cm^2 nearly twice that of the ASTM required; unit moisture loss. There was a slight difference in the Ka value of top and bottom of 1.1 x 10^{-6} cm^2/sec, which is well below the 3.7 x 10^{-6} cm^2/sec Ka value difference indicating marginal performance. A greater difference in Ka values was expected for this curing compound.

35. The test results for WES-CC-2R3 is shown in Figure 12. This curing compound would not be considered a satisfactory curing compound by today's standards. The difference in the Ka value of the top and bottom was 3.5 x 10^{-6} cm^2/sec, which is slightly below the 3.7 x 10^{-6} cm^2/sec Ka value difference indicating marginal performance. If the test specimen had been 3-1/2 in. in depth, this may have increased the Ka difference to some degree.

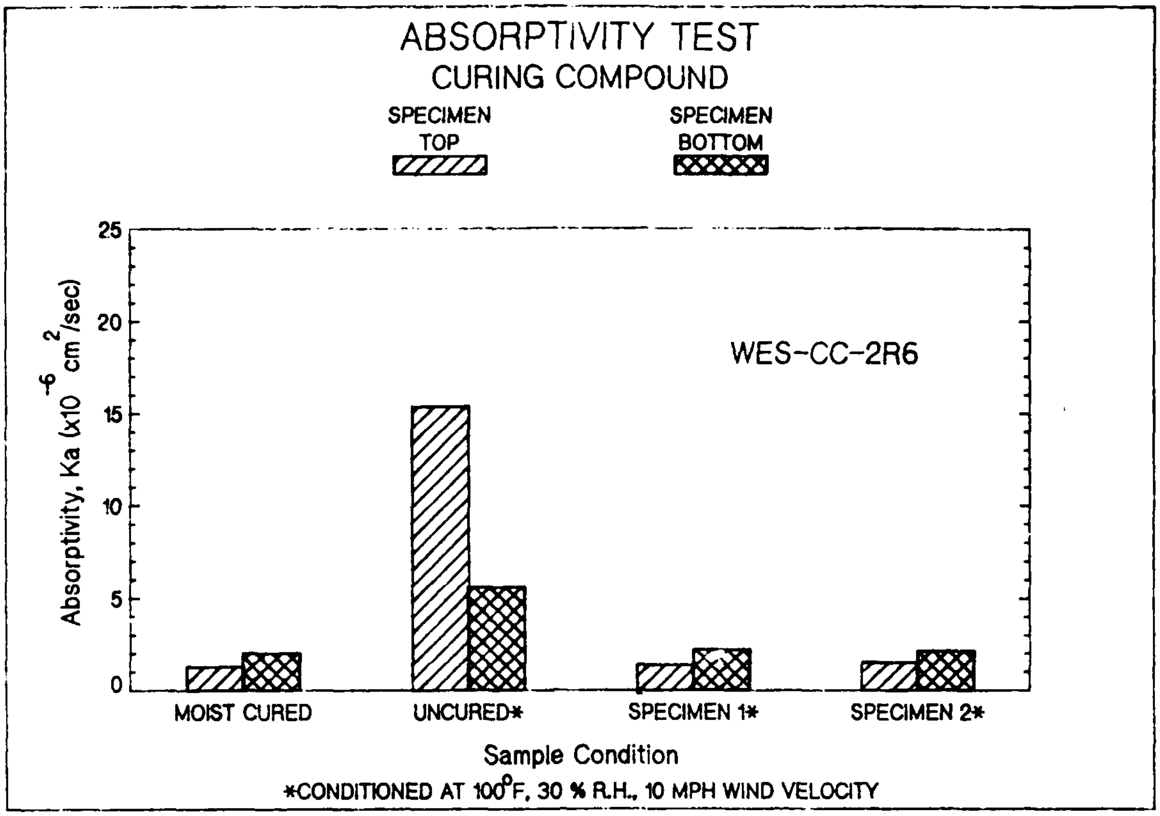


Figure 10. Absorptivity test results for curing compound WES-CC-2R6

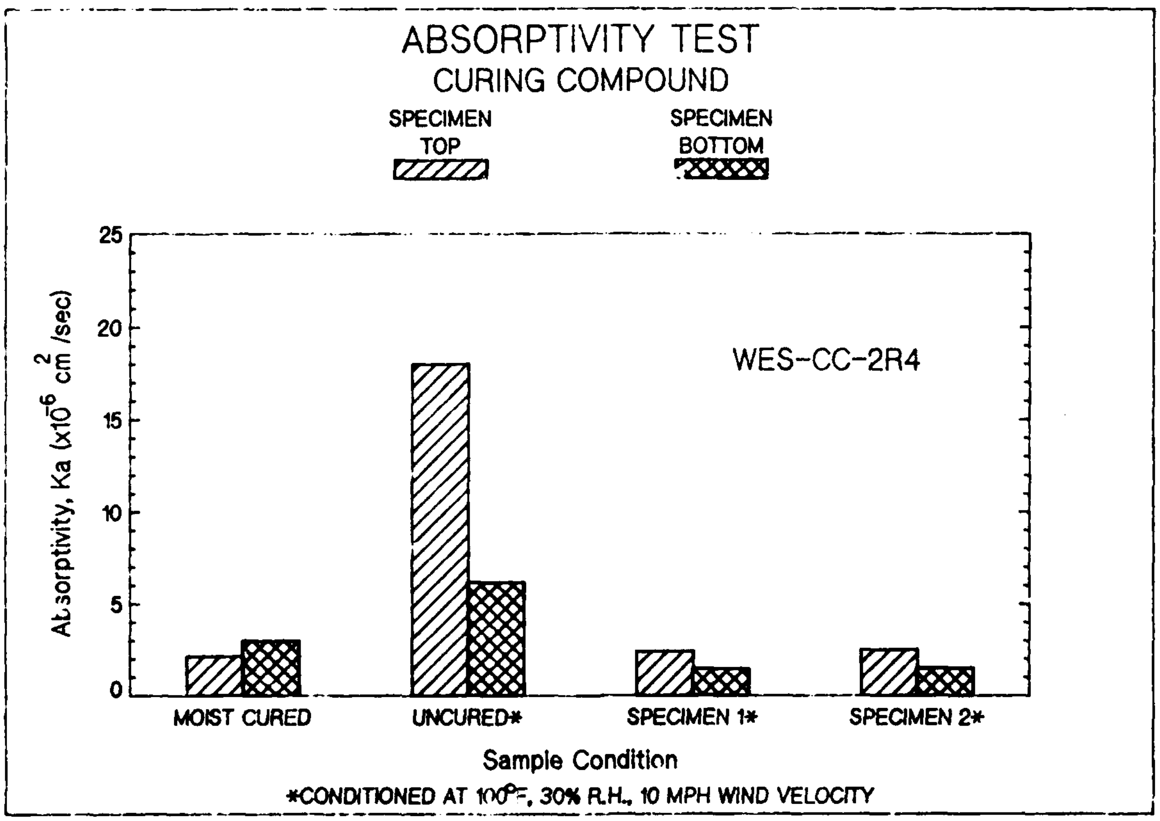


Figure 11. Absorptivity test results for curing compound WES-CC-2R4

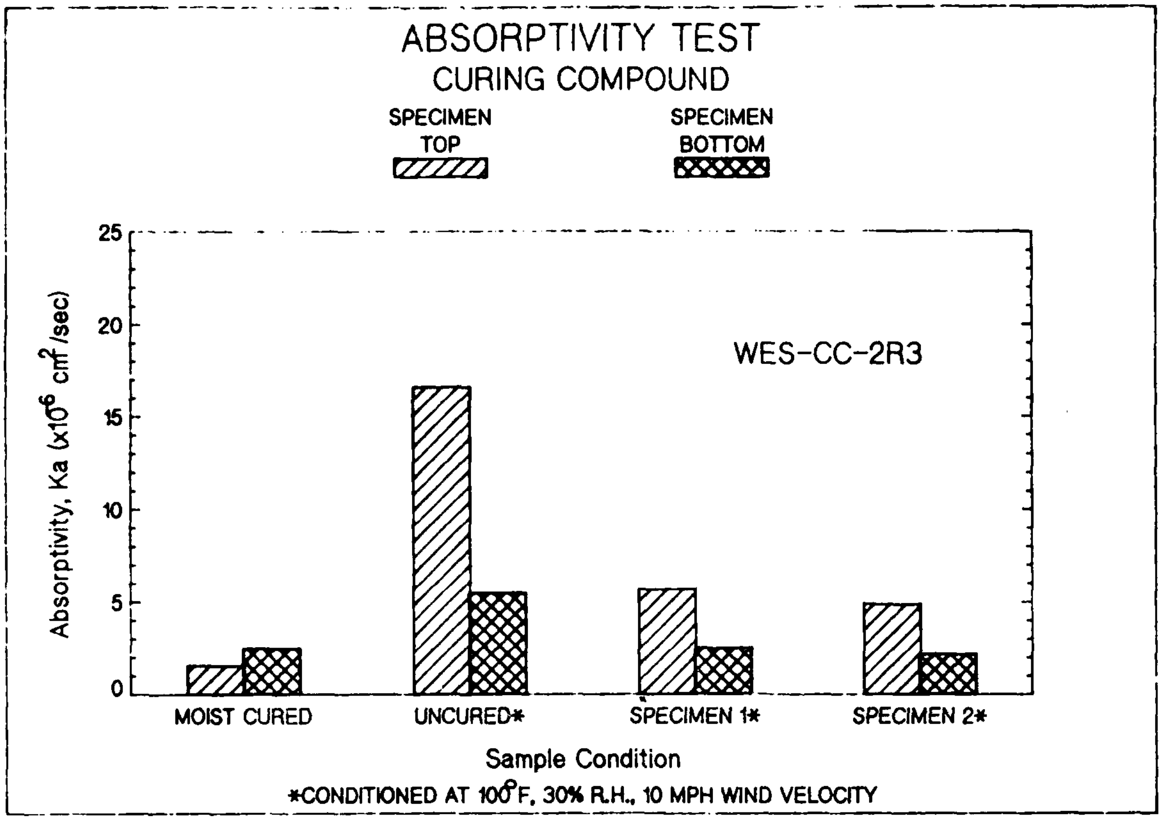


Figure 12. Absorptivity test results for curing compound WES-CC-2R3

Abrasion Test Method

36. Mortar test slabs which had been coated with curing compounds, and which were not coated, were placed in the curing compound cabinet for 7 days then tested for surface abrasion using the rotating-cutter test method. Very little difference in surface abrasion could be noticed between the cured and uncured test specimens. The small difference was contributed to the bottom of the test specimen not being level, and the total depth of abrasion which was approximately 1/8 in.

37. Since we could not obtain the desired depth of abrasion using the rotating-cutter test method, the core barrel abrasion test method developed by WES was used in determining the effectiveness of cure of mortar using different curing methods. A mold was constructed of coated plyboard to obtain a test mortar slab that would have a smooth bottom surface. The inside dimension of the form was 12 by 8 by 2 in. The mortar mixture was the same as the one used for the absorptivity test. The curing compound WES-CC-9R was

selected for evaluation, since this curing compound failed to meet the unit moisture loss requirements of CRD-C 300 (USAEWES 1949a), and did meet the unit moisture loss requirements of ASTM C 309 (ASTM 1989a), and was found to have a unit loss of 0.052 g/cm^2 which was near the upper limit of the ASTM specification.

38. Three test specimens were cast from the mortar mixture. All edges of the wood form were sealed with wax before the mortar was placed into the form. The mortar test specimens were placed in a moist area (large plastic container, containing water and covered with plastic) for 4 hr after casting. A V-shaped groove approximately 1/8 in. in depth was formed between the edge of the mortar specimens and the mold, and the groove sealed with a sealing compound. The surface of one test specimen was coated with the curing compound using a paint sprayer. The coated test specimen and one of the uncoated test specimens were placed in an environmental chamber at 100° F and 30 percent R.H. The other uncoated test specimen was placed in a moist curing cabinet at 72° F and 95 percent R.H.

39. After 7 days the test specimens were removed and tested for abrasion resistance using the core barrel test method. Six areas on the surface of each test specimen were tested, and the areas tested were at least 1 in. from the edge of the test specimen. The average of the six readings were taken and the mean reported. The test above was duplicated the following week to determine the reproducibility of the test. The test results from the second set of test specimens was found to be very close to the test results of the first set of test specimens indicating that good precision might be obtained using this test method. The test results of the first set of test specimens is shown in Figure 13.

40. The abrasion resistance of the mortar test specimen cured with the curing compound WES-CC-9R was found to be nearly identical to the test specimen which was moist cured. The depth of abrasion with time was significantly higher for the uncured test specimen. The depth of abrasion with time decreased with depth for the uncured test specimen which was expected. The following tabulation lists the depth of abrasion at different increments of time.

Increments of time, sec	Depth of abrasion, in.		
	Uncured	Moist Cured	Curing Compound
0-40	0.49	0.27	0.27
40-80	0.28	0.24	0.23
80-120	0.32	0.22	0.22

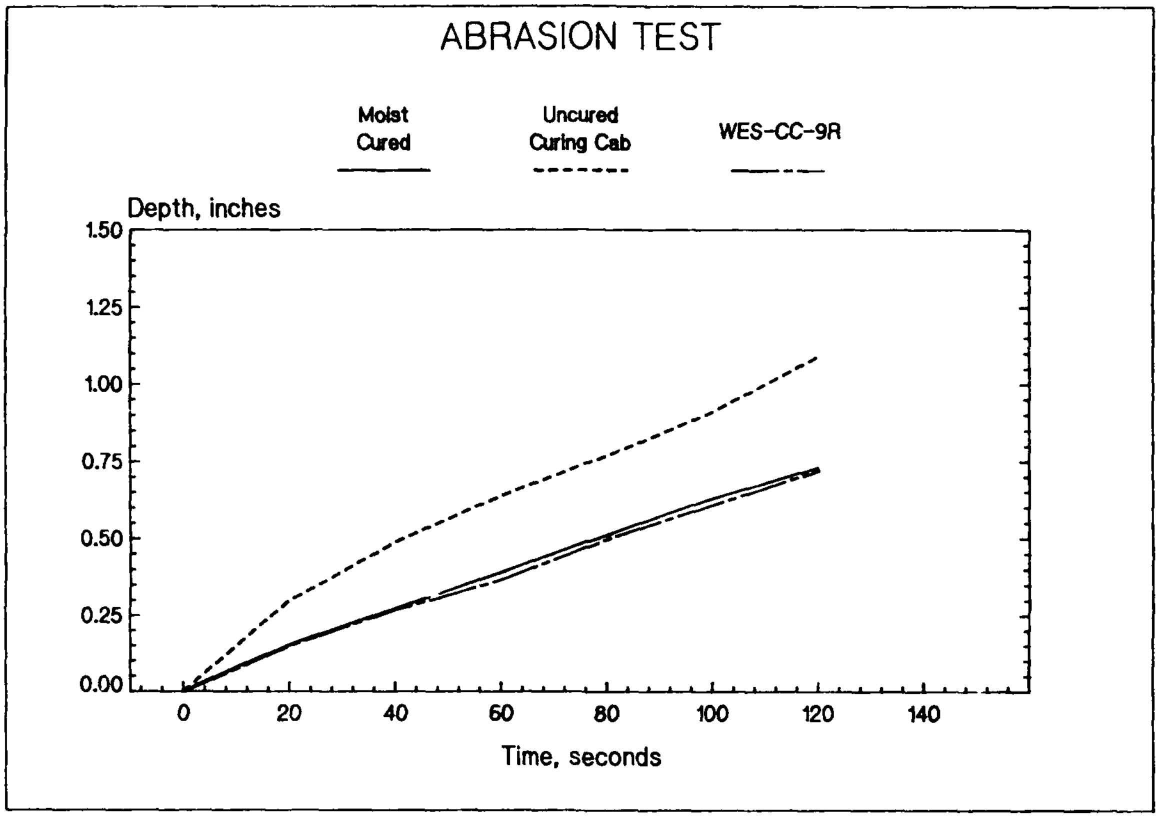


Figure 13. Abrasion test results

PART VI: SUMMARY

41. Different test methods for evaluating the effectiveness of cure of portland-cement mortar were investigated that included: water absorptivity at different depths, capillary porosity at different depths, combined water, splitting tensile strength, and surface abrasion. Evaluations of these test methods were made by comparing differences in values obtained from each test method for test specimens placed in a moist environment and placed in environmental cabinets conditioned at 100° F and 30 percent R.H. with and without (10 mph) wind.

42. The water absorptivity test method evaluated was a modification of a proposed ASTM method for evaluating the effectiveness of materials for curing concrete. A 2-in. core was taken from the test specimen instead of the specified 1-in. core, and the mortar mixture proportions were changed slightly to obtain a mortar containing a slightly higher amount of paste. A small table saw was used in place of the specified precision saw. Modifications were made due to variability in test results following the proposed test method except for the table saw. The variability of test results were reduced significantly when making the modifications. The modified proposed ASTM method was found to be a good indicator of quality of mortar when comparing test results obtained of cured and uncured mortar.

43. Capillary porosity measurements made near the top and bottom of the mortar test specimens were also found to be a good indicator of the quality of mortar. Higher capillary porosity values were obtained for the top portion of the uncured mortar test specimens which was expected since capillary porosity would be related to absorptivity. This test method shows good correlation with the absorptivity test method, but takes longer to complete the test, and laboratory personnel have to handle specimens soaked in a chlorinated hydrocarbon.

44. Differences in combined water of cured and uncured mortar could be detected, but the differences were small. The time to complete this test was nearly equal to the two tests previously discussed. Only a few specimens were tested during this study using this method and more testing would be necessary in order to determine the validity of this test method.

45. Two physical test methods, splitting tensile strength and abrasion

resistance, were evaluated in hopes of finding a test method to correlate test results with the absorptivity test results on the effectiveness of curing. A large variation in test results were found for the few cores tested for splitting tensile strength, and because of the variation in test results no further testing was performed. Two abrasion test methods, an ASTM method (rotating cutter) and a core barrel method developed by WES was evaluated. The total depth of abrasion when using the rotating cutter was approximately 1/8 in. and a greater depth of abrasion was desired. A significant difference in abrasion rate with depth was noted for cured and uncured mortar when using the core barrel method.

46. Nine curing compounds were obtained to determine their effectiveness in curing mortar test specimens using the absorptivity test method. Two of the curing compounds met the requirements of CRD-C 300 (USAEWES 1949a) and six of the curing compounds met the requirements of ASTM C 309 (ASTM 1989a). One of the curing compounds did not meet either requirement. One of the curing compounds meeting the requirement of CRD-C 300 was diluted with the solvent, furnished by the manufacturer, to obtain three curing compound mixtures that would fail the requirements of both specifications.

47. Test results obtained from the absorptivity test method indicated that curing compounds meeting the requirements of both ASTM C 309 and CRD-C 300 were effective in curing mortar test specimens. Two of the curing compounds prepared by dilution were also found to be effective in curing mortar test specimens. The unit moisture loss for these two curing compounds when tested according to ASTM C 156 (ASTM 1989e) were found to be 0.068 and 0.098 g/cm^2 which is greater than the ASTM C 309 required value of 0.055 g/cm^2. The other curing compound prepared by dilution was not found to be effective for curing mortar test specimens. This curing compound was found to have a unit moisture loss of 0.140 g/cm^2 when tested according to ASTM C 156. A sodium silicate solution recommended by the manufacturer as hardener and sealer compound was tested and found to be ineffective for curing mortar test specimens.

48. Mortar test specimens cured with a curing compound having a unit moisture loss of 0.052 g/cm^2, which is near the upper limit of the ASTM requirement, were tested by the abrasion test developed by WES. Mortar test specimens that were moist cured and placed in an environment at 100° F and

30 percent R.H. were tested along with the specimens cured with the curing compound. The rate of abrasion (depth with time) was found to be nearly identical for the moist cured and curing compound coated test specimens. There was a significant difference in the rate of abrasion of these specimens compared to the uncured test specimens which was much greater. This test also indicated that curing compounds meeting the requirements of ASTM C 309 are effective in curing mortar.

49. The abrasion test was developed near the end of the study and there was not enough time to thoroughly evaluate this test method. This test method shows promise as a way to determine the effectiveness of cure and is less time consuming than the absorptivity test method.

PART VII: CONCLUSIONS AND RECOMMENDATIONS

50. Curing compounds meeting the requirements of ASTM C 309 (ASTM 1989a) were found to be apparently as effective as curing compounds meeting the requirement of CRD-C 300 (USAEWES 1949a) for curing concrete based on absorptivity and abrasion testing. Based on these tests, curing compounds meeting the requirements of either specification should be satisfactory for curing concrete, if properly employed in the field.

51. The absorptivity test method (Proposed ASTM Method) was found to be a good indicator for evaluating the effectiveness of cure based on test results for both moist cured and uncured test specimens. Modifications made to the test method improved the precision. These modifications may not have been necessary if a precision saw had been used as recommended in the test method. Curing compounds of poorer quality than those specified by ASTM C 309 were found to be effective in curing when using this test method, therefore, this test method is not recommended as a standard for ASTM or Corps specifications.

52. The abrasion test developed by WES was not evaluated until the study was nearly complete and there was not enough time to thoroughly evaluate this method. This test method shows promise as a method to determine the effectiveness of cure and is less time consuming than the absorptivity test method. It is recommended that further tests be made with this test method using curing compounds having a wide range of unit moisture loss, as determined by ASTM C 156 (ASTM 1989e), which are above the required limit to determine an upper unit moisture loss value.

53. It is also recommended that curing compounds be tested that are applied to surfaces having deep textures such as broomed surfaces common to pavements. Woodstrom and Neal (1976) reported that certain types of curing compounds provide better coverage on the high points of deep textured surfaces and recommends their use with this type of texture.

REFERENCES

ACI Committee 308. 1989. "Standard Practice for Curing Concrete," ACI 308-81, Part 2, ACI Manual of Concrete Practice.

American Society of Testing Materials. 1988. "Proposed Test Method for Evaluating the Effectiveness of Materials for Curing Concrete," C-9 Proposal P 198, 1988 Book of ASTM Standards, Vol 40.02, pp 690-692, Philadelphia, PA.

_________. 1989a. "Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete," Designation: C 309-89, 1989 Book of ASTM Standards, Vol 04.02, pp 182-184, Philadelphia, PA.

_________. 1989b. "Standard Test Method for Abrasion Resistance of Concrete by Sandblasting," Designation: C 418-89, 1989 Book of ASTM Standards, Vol 04.02, pp 219-221, Philadelphia, PA.

_________. 1989c. "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens," Designation: C 496-86, 1989 Book of ASTM Standards, Vol 04.02, pp 259-267, Philadelphia, PA.

_________. 1989d. "Standard Test Method for Abrasion Resistance of Concrete or Mortar Surfaces by the Rotating-Cutter Method," Designation: C 944-80, 1989 Book of ASTM Standards, Vol 04.02, pp 476-478, Philadelphia, PA.

_________. 1989e. "Standard Test Method for Water Retention by Concrete Curing Materials," Designation: C 156-89, 1989 Book of ASTM Standards, Vol 04.02, pp 94-96.

Figg, J. W., and Bowden, S. R. 1971. "The Analysis of Concretes," Building Research Station: Department of the Environment, Her Majesty's Stationary Office, London, England.

Senbetta Ephraim. 1981 (Aug). "Development of a Laboratory Technique to Quantify Curing Quality," Joint Highway Research Project, JHRP-81-16, Purdue University; Discussion by Bryant Mather, "Curing Compounds," Concrete International, Feb 1989, Vol 12, No. 2, pp 40-41.

US Army Engineer Waterways Experiment Station. 1949a (Aug). "Specifications for Membrane-Forming Compounds for Curing Concrete," CRD-C 300-88, Handbook for Concrete and Cement, Vicksburg, MS.

_________. 1949b (Aug). "Test Method for Sprayability and Unit Moisture Loss Through the Membrane Formed by a Concrete Curing Compound," CRD-C 302-79, Handbook for Concrete and Cement, Vicksburg, MS.

Woodstrom, J. H., and Neal, B. F. 1976 (Dec). "Curing Compounds for Portland Cement Concrete," Report No. CA-DOT-TL-5149-2-76-3, California Department of Transportation, Sacramento, CA.

Table 1

TO: Billy Neeley, Structures Laboratory	REPORT OF TEST OF HYDRAULIC CEMENT WES-48, C-1	FROM: STRUCTURES LABORATORY, USAE WATERWAYS EXPERIMENT STATION, ATTN: CEMENT AND POZZOLAN UNIT, PO BOX 631, VICKSBURG, MISSISSIPPI 39180-0631

COMPANY: Lone Star	BIN NO. single sample	TEST REPORT NO. WES-6-87
LOCATION: Cape Girardeau, MO	TONS REPRESENTED:	DATE: 10 Feb 87
SPECIFICATION: ASTM C 150, I		DATE SAMPLED: 22 Jan 87

TEST RESULTS OF THIS SAMPLE LOT [XX] COMPLY [ ] DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)

SAMPLE NO.	1							
SiO_2, %	21.5							
Al_2O_3, %	4.5							
Fe_2O_3, %	2.5							
CaO, %	63.2							
MgO, %	3.9							
SO_3, %	2.4							
LOSS ON IGNITION, %	0.6							
INSOLUBLE RESIDUE, %	0.11							
Na_2O, %	0.05							
K_2O, %	0.79							
ALKALIES-TOTAL AS Na_2O, %	0.57							
C_3S, %	52							
C_3A, %	8							
C_2S, %	22							
$C_3A + C_3S$, %	60							
C_4AF, %	7							
$C_4AF + 2 C_3A$, %	24							
HEAT OF HYDRATION, 7D, CAL/G								
HEAT OF HYDRATION, 28D, CAL/G								
SURFACE AREA, m^2/kg (AP) OR SQM/KG (AP)	385							
AIR CONTENT, %	9							
COMP. STRENGTH, 3 D, PSI	3240							
COMP. STRENGTH, 7 D, PSI	4340							
COMP. STRENGTH, D, PSI								
FALSE SET-PEN. F/1,%								
SAMPLE NO.								
AUTOCLAVE EXP., %	0.12							
INITIAL SET, MIN (GILLMORE)	155							
FINAL SET, MIN (GILLMORE)	310							
TiO_2	0.17							
P_2O_5	0.02							

REMARKS QE7G729S2170001

Toy S. Poole

Toy S. Poole
Chief, Cement and Pozzolan Unit

Table 2

Description of Curing Compounds

Curing Compound	Type Vehicle Solid	Manufacturers Description
WES-CC-1R	Wax	White pigmented, complies with CRD-C 300
WES-CC-2R	Wax	Clear, complies with CRD C 300
WES-CC-3R	Resin rubber copolymer	Clear, complies with ASTM C 309, Type 1 and 1D, Class B and the former Federal Specification TTC-800A*, Type 1
WES-CC-4R	Resin	Clear, complies with ASTM C 309, Type 1 and 1D
WES-CC-5R	Styrene-butadiene	Clear, complies with ASTM C 309, Types 1 and 1D, Class B and the former Federal Specification TTC-800A*, Type 1
WES-CC-6R	Acrylic copolymer	Clear, complies with ASTM C 309, Types 1 and 1D, Class B
WES-CC-7R	Sodium silicate	Recommended as a hardener, sealer* and dust proofing compound
WES-CC-8R	Acrylate	Clear, complies with ASTM C 309, Type 1, Class B and the former Federal Specification TTC-800A*
WES-CC-9R	Acrylate	Clear, complies with ASTM C 309, Type 1, Class B

* TTC-800A was cancelled on 31 Oct 1978.

Table 3

Curing Compound Test Results

	Non-Volatile Content, %	Unit Moisture Loss, g/cm^2	
		ASTM C 156	CRD-C 302
WES-CC-1R	36	-	0.017
WES-CC-2R	33	-	-0.024
WES-CC-2R6	20	0.068	0.078
WES-CC-2R4	14	0.098	-
WES-CC-2R3	10	0.140	-
WES-CC-3R	21	0.028	0.044
WES-CC-4R	24	0.036	0.045
WES-CC-5R	19	0.039	0.046
WES-CC-6R	15	0.044	0.060
WES-CC-7R	15	0.170	-
WES-CC-8R	31	0.029	0.040
WES-CC-9R	15	0.052	0.066

Unit moisture loss requirements:
ASTM C 309 0.055 g/cm^2
CRD-C 300 0.031 g/cm^2

Table 4

Absorptivity Test Results Cured at 3 Conditions

1-in. Core, Pail Mixer

Test Slab	Mortar Batch	Core No.	Curing Condition	Ka ($x 10^{-6}$ cm^2/sec) Depth from Surface, cm 0.5	1.5	2.6	3.7	4.8
1	1	1	Moist Cured	2.4	1.4	2.6	4.7	1.8
		2		5.0	1.2	1.9	2.9	-
4	2	1	Moist Cured	7.2	17.0	6.0	1.0	1.2
		2		1.4	3.7	6.3	2.0	1.8
2	1	1	Laboratory Air	15.0	2.2	1.1	1.4	1.8
		2		12.6	1.5	3.0	1.1	1.2
5	2	1	Laboratory Air	14.4	4.2	2.3	2.0	2.2
		2		9.4	5.4	3.6	2.2	3.0
3	1	1	Curing Compound Cab	16.8	25.3	6.4	7.5	1.8
		2		9.8	11.7	10.9	11.8	7.8
6	2	1	Curing Compound Cab	24.4	5.1	12.5	8.8	2.7
		2		21.0	15.0	8.5	2.7	8.0

Table 5

Absorptivity Test Results Cured at 3 Conditions

1-in. Core, Hobart Mixer

Test Slab	Mortar Batch	Core No.	Curing Condition	Ka ($x 10^{-6}$ cm^2/sec) Depth from Surface, cm 0.5	1.5	2.5	3.5	4.5
7	1	1	Moist Cured	2.4	3.3	3.6	2.0	1.9
		2		3.0	2.8	4.0	2.8	3.4
8	1	1	Laboratory Air	9.3	3.0	3.7	3.4	2.6
		2		10.3	4.3	7.0	3.8	2.9
9	2	1	Curing Compound Cab	20.8	6.6	7.6	4.3	2.7
		2		15.8	7.8	6.3	5.0	3.4
10	2	1	Curing Compound Cab	28.0	6.5	4.8	3.0	3.3
		2		17.0	12.1	8.2	6.4	5.2

Table 6

Absorptivity Test Results Cured at 2 Conditions

2-in. Core

Test Slab	Curing Condition	Ka (x 10^{-6} cm^2/sec) Top	Bottom	Difference
11	Moist Cured	2.6	2.1	0.5
12		1.4	1.2	0.2
13	Curing Compound Cab	29.5	4.7	24.8
14		18.6	2.4	16.2

* Average of 2 cores taken from each specimen.

Table 7

Absorptivity Test Results Cured at 2 Conditions

2-in. Core

Test Slab	Curing Condition	Ka (x 10^{-6} cm^2/sec) Top*	Bottom*	Difference
15	Moist Cured	1.4	1.3	0.1
16		1.8	1.5	0.3
17		1.4	1.1	0.3
18		1.6	1.8	0.2
19	Curing Compound Cab	13.6	4.7	8.9
20		12.9	4.1	8.8
21		16.9	5.2	11.7
22		11.9	3.4	8.5

* Average of 4 cores taken from each specimen.

Table 8

Absorptivity Test Results Cured at 100° F and 30 percent R. H.

2-in. Core

Test Slab	Ka ($x\ 10^{-6}\ cm^2/sec$) Top	Bottom	Difference
23	17.0	4.8	12.2
24	17.6	5.1	12.5
25	16.1	4.2	11.9
26	15.2	3.8	11.4

Table 9

Capillary Porosity Test Results Cured at 2 Conditions

Different Pressures for Soaking

Vacuum in., Hg	Curing Condition	Test Slab	Capillary Porosity, $cm^3/100\ g$ Top*	Bottom*	Δ
28	Moist Cured	27	8.46	7.59	0.87
	Curing Cabinet	28	9.76	8.27	1.49
20	Moist Cured	29	6.37	6.63	-0.26
	Curing Cabinet	30	9.63	7.47	2.16
2	Moist Cured	31	2.79	2.58	0.21
	Moist Cured	33	3.11	2.81	0.30
2	Curing Cabinet	32	4.53	2.82	1.71
	Curing Cabinet	34	5.18	3.25	1.93

* Each value the average of 2 test specimens.

Table 10

Capillary Porosity Test Results Cured at 2 Conditions

Curing Condition	Test Slab	Capillary Porosity, $cm^3/100$ g Top*	Bottom*	Δ
Moist Curing	35	2.27	2.08	0.19
	37	3.39	3.26	0.13
	39	2.96	2.92	0.04
	41	3.00	2.57	0.49
	43	2.89	2.60	0.29
Curing Cabinet	36	5.55	3.38	2.17
	38	5.86	3.63	2.23
	40	4.82	2.61	2.21
	42	5.78	3.38	2.40
	44	5.39	3.64	1.75

* Each value the average of 2 test specimens.

Table 11

Splitting Tensile Strength

Test Slab	Splitting Tensile Strength, psi	Average
No. 1 Moist Cured	360, 305, 300	320
No. 2 Moist Cured	310, 280, 215*	295
No. 3 Curing Compound Cabinet	265, 210, 220	230
No. 4 Curing Compound Cabinet	275, 285, 245	270

* Bad break omitting from average.